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PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

United States Patent and Trademark Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ÉTATS-UNIS D'AMÉRIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 08 July 1999 (08.07.99)	
International application No. PCT/KR98/00376	**Applicant's or agent's file reference** SH-11357-PCT
International filing date (day/month/year) 24 November 1998 (24.11.98)	**Priority date** (day/month/year) 25 November 1997 (25.11.97)
Applicant KIM, Dong, Kyu et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

21 June 1999 (21.06.99)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer C. Carrié
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:

LEE Young Pil
The Cheonghwa Bldg.,
1571-18 Seocho-dong, Seocho-gu
Seoul, 137-073
Republic of Korea

Y.P. LEE & ASSOCIATES
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NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

Applicant's or agent's file reference SH-11357-PCT	Date of mailing *(day/month/year)* 24 Feb. 1999 (24.02.99) FOR FURTHER ACTION See paragraphs 1 and 4 below
International application No. PCT / KR 98/00376	International filing date *(day/month/year)* 24 Nov. 1998 (24.11.98)
Applicant SAMSUNG ELECTRONICS CO., LTD. et al.	

1. [X] The applicant is hereby notified that the international search report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] With regard to the protest against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

[ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

[ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the ISA/ AT AUSTRIAN PATENT OFFICE Kohlmarkt 8-10 A-1014 Vienna	Authorized officer Wolf
Facsimile No. +43 / 1 / 534 24 - 535	Telephone No. +43 / 1 / 534 24 - 436

Form PCT/ISA/220 (July 1998)

(See notes on accompanying sheet)

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the *PCT Applicant's Guide*, a publication of WIPO.

In these Notes, "Article," "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended ?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Preliminary Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When ? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments ?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How ? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments ?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
SH-11357-PCT		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/KR 98/00376	24 November 1998 (24.11.98)	25 November 1997 (25.11.97)
Applicant		
Samsung Electronics Co., Ltd. et al.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

2. ☐ Certain claims were found unsearchable (See Box I).

3. ☐ Unity of invention is lacking (See Box II).

4. With regard to the title,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the abstract,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No. 2

   ☒ as suggested by the applicant.

   ☐ because the applicant failed to suggest a figure.

   ☐ because this figure better characterizes the invention.

   ☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR 98/00376

A. CLASSIFICATION OF SUBJECT MATTER

IPC[6]: H 04 J 11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[6]: H 04 J 11/00, H 04 H 1/00, H 04 L 5/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 683 576 A1 (HITACHI) 22 November 1995 (22.11.95), fig. 4; page 5, line 54 - page 6, line 32.	1,3
A	WO 92/10 043 A1 (THOMSON-CSF) 11 June 1992 (11.06.92), fig. 2,3; abstract.	1,3,4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 February 1999 (22.02.99)	24 February 1999 (24.02.99)

Name and mailing address of the ISA/ AT	Authorized officer
Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna	Dröscher
Facsimile No. 1/53424/535	Telephone No. 1/53424/320

Form PCT/ISA/210 (second sheet) (July 1998)

In Recherchenbericht angeführtes Patentdokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
EP A1 683576	22-11-95	JP A2 7321763	08-12-95
WO A1 9210043	11-06-92	AT E 148970	15-02-97
		AU A1 90918/91	25-06-92
		AU B2 641071	09-09-93
		CA AA 2073777	31-05-92
		DE C0 69124690	27-03-97
		DE T2 69124690	05-06-97
		EP A1 513313	19-11-92
		EP B1 513313	12-02-97
		ES T3 2098490	01-05-97
		FI A 923426	29-07-92
		FI A0 923426	29-07-92
		FR A1 2670062	05-06-92
		FR B1 2670062	12-11-93
		JP T2 5504037	24-06-93
		NO A 922959	27-07-92
		NO A0 922959	27-07-92
		SG A1 46723	20-02-98
		US A 5313169	17-05-94

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(30) Priority Data:
1997/62690 25 November 1997 (25.11.97) KR

(71) Applicant *(for all designated States except US)*: SAMSUNG ELECTRONICS CO., LTD. [KR/KR]; 416, Maetan-dong, Paldal-gu, Suwon-city, Kyungki-do 442-370 (KR).

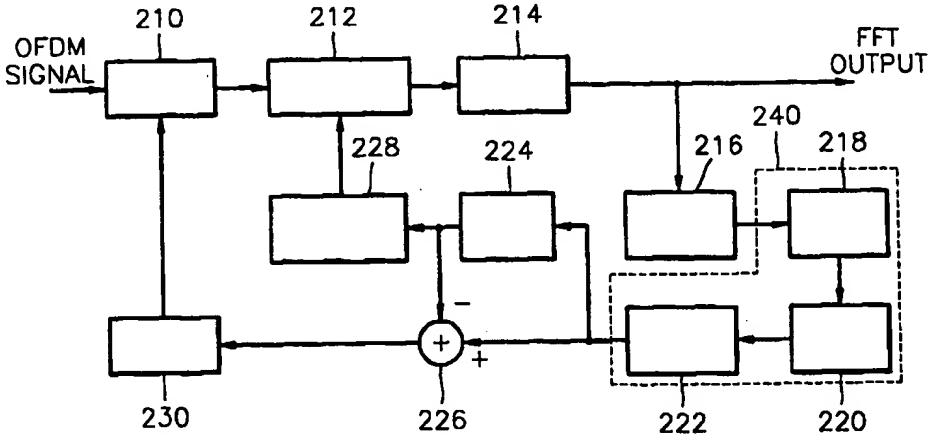
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: KIM, Dong, Kyu [KR/KR]; 416, Maetan-dong, Paldal-gu, Suwon-city, Kyungki-do 442-370 (KR). DO, Sang, Hyun [KR/KR]; 416, Maetan-dong, Paldal-gu, Suwon-city, Kyungki-do 442-370 (KR). CHOI, Hyung, Jin [KR/KR]; 416, Maetan-dong, Paldal-gu, Suwon-city, Kyungki-do 442-370 (KR).

(74) Agent: LEE, Young, Pil; The Cheonghwa Building, 1571-18, Seocho-dong, Seocho-gu, Seoul 137-073 (KR).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING RECEIVER WHERE FFT WINDOW POSITION RECOVERY INTERLOCKS WITH SAMPLING CLOCK ADJUSTMENT AND METHOD THEREOF



(57) Abstract

An OFDM receiver for interlocking FFT window position recovery with sampling clock control, and a method thereof are provided. This method includes the steps of: extracting a pilot signal from fast-Fourier-transformed OFDM received signals, and detecting inter-pilot phase differences; averaging the detected phase differences for a symbol and normalizing the mean phase difference by dividing it into reference values corresponding to phase differences generated when FFT window errors of at least one sample exist; and simultaneously controlling the FFT window position offset using a value obtained by rounding off the normalized value, and the sampling clock offset using the difference between the round-off value and the normalized value.

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING RECEIVER WHERE FFT WINDOW POSITION RECOVERY INTERLOCKS WITH SAMPLING CLOCK ADJUSTMENT AND METHOD THEREOF

Technical Field

The present invention relates to an orthogonal frequency division multiplexing (OFDM) receiver and a method thereof, and more particularly, to an OFDM receiver for interlocking FFT window position recovery with sampling clock control for controlling an analog-to-digital converter, and a method thereof.

Background Art

Generally, time synchronization and frequency synchronization must be accurately performed to allow a receiver to recover an OFDM signal for European digital broadcasts transmitted from a transmitter. Time synchronization consists of FFT window position recovery for accurate parallel processing of signals, and sampling clock recovery for controlling a sampling clock of an analog-to-digital converter (ADC) for sampling a signal having a maximum signal-to-noise ratio (SNR) among received signals. Frequency synchronization means that the radio frequency (RF) oscillation frequency of a receiver is synchronized with the oscillation frequency of a transmitter.

FIG. 1 is a block diagram of a portion for carrying out FFT window position recovery and sampling clock control in a general OFDM system receiver.

When the number of bins of FFT is N, the symbol of an OFDM signal is comprised of a useful data interval having N useful data samples being the outputs of an inverse fast Fourier transform (IFFT), and a guard interval having G sample lengths to be inserted between symbols to prevent inter-symbol interference. The guard interval copies the end portion of the useful data interval. A transmitter (not shown) sequentially transmits a symbol consisting of G+N samples being the sum of N complex values and G

complex values output by the IFFT.

An i-th symbol comprised of complex values output by an FFT is expressed by the following Equation 1:

$$s_l = \sum_{n=-G}^{N-1} x_{l,n} = \sum_{n=-G}^{-1} \sum_{k=0}^{N-1} X_{l,k} e^{j2\pi(N+n)l/N} + \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} X_{l,k} e^{j2\pi kn/N} \quad \ldots(1)$$

wherein l is a symbol number, k is a carrier index (number), N is the number of useful data samples, and n represents sampling time. The first term of the second expression of Equation 1 represents a guard interval, and the second term represents a useful data interval.

As shown in FIG. 1, an ADC 110 samples a received OFDM signal. An FFT window 120 is controlled by an FFT window controller 180 to recover an FFT window position, and removes the guard interval of the first term of Equation 1 and then sequentially transmits the second term to the FFT 130. A phase difference calculator 150 calculates a phase difference between two pilots extracted by a pilot extractor 140 for one symbol. An FFT window offset detector 160 detects the position of the FFT window by the phase difference output by the phase difference calculator 150. The FFT window controller 180 controls the position of the FFT window by the FFT window offset. When FFT window position recovery is not carried out well, the received signal cannot be accurately recovered since sampling clock control is also not carried out well. Hence, the sampling clock control starts after FFT window position recovery by the FFT window controller 180 is completed. In other words, the phase difference calculator 150 calculates phase differences between pilots extracted between current and previous symbols by the pilot extractor 140 after the FFT window position recovery is completed. A sampling clock offset detector 170 detects sampling offsets using the phase difference output by the phase difference calculator 150. A phase-locked loop (PLL) 190 controls the sampling clocks of the ADC 110 according to input sampling clock offsets. If the sampling clocks are not controlled, the receiver is not sampled into a total of (N+G) samples for one symbol but sampled into (N+G+1) or (N+G−1) samples because of a

sampling clock difference between the receiver and transmitter, resulting in a sample stuff-rob phenomenon. As a consequence, a next symbol start point is preceded or delayed by one sample. Therefore, the apparatus of FIG. 1 controls sampling clock errors after accurate FFT window position recovery is carried out, and thus the sample stuff-rob phenomenon is generated while FFT position recovery is performed.

Disclosure of the Invention

It is an object of the present invention to provide an OFDM receiver for simultaneously carrying out FFT window position recovery and sampling clock control using a detected phase difference between two pilots in one symbol period, and a method thereof.

To accomplish the above object, there is provided a method of interlocking FFT window position recovery with sampling clock control in symbol units in an orthogonal frequency division multiplexing (OFDM) receiver for receiving an OFDM symbol consisting of a useful data interval and a guard interval, the method comprising the steps of: (a) extracting a pilot signal from fast-Fourier-transformed OFDM received signals, and detecting inter-pilot phase differences; (b) averaging phase differences detected in step (a) for a symbol and normalizing the mean phase difference by dividing it into reference values corresponding to phase differences generated when FFT window errors of at least one sample exist; and (c) simultaneously controlling the FFT window position offset using a value obtained by rounding off the normalized value of the step (b), and the sampling clock offset using the difference between the round-off value and the normalized value.

To accomplish the above object, there is provided an OFDM receiver for interlocking FFT window position recovery with sampling clock control by receiving an OFDM symbol consisting of a useful data interval and a guard interval, the apparatus comprising: an analog-to-digital converter (ADC) for converting an OFDM signal into digital complex samples; an FFT window for removing the guard interval from the digital complex samples output by the

ADC and outputting useful data samples; an FFT for fast-Fourier-transforming the samples output by the FFT window; a phase difference calculator for calculating phase differences between two values among the complex values received via a plurality of pilots from the FFT, averaging these phase differences for one symbol, and normalizing the mean value by dividing it into predetermined reference values; an FFT window controller for rounding off the normalized value output by the phase difference calculator and controlling the window position of the FFT window; and a phase synchronous loop for controlling the sampling clock signals of the ADC using the difference between the round-off value and the normalized value.

Brief Description of the Drawings

FIG. 1 is a block diagram showing the configuration of a general OFDM system receiver;

FIG. 2 is a block diagram of an OFDM receiver for interlocking FFT window position recovery with sampling clock control, according to the present invention;

FIG. 3 is a conceptual view showing the division of time synchronization into an FFT window offset and a sampling clock offset by using the round-off calculator 224 and the subtractor 226 of FIG. 2;

FIG. 4A is a graph showing outputs of the phase difference calculator vs. FFT window offsets, according to the present invention;

FIG. 4B is a graph showing inputs of the FFT window controller vs. FFT window offsets, according to the present invention; and

FIG. 4C is a graph showing inputs of the PLL for controlling sampling clock signals vs. FFT window offsets, according to the present invention.

Best mode for carrying out the Invention

Referring to FIG. 2, an ADC 210 converts a received OFDM signal into a digital complex sample. An FFT window 212 removes a guard interval from the input digital complex sample and then sequentially outputs N sample values to an FFT 214. The FFT 214 fast-Fourier-transforms the

input N sample values.

A pilot extractor 216 extracts complex values transmitted via pilots, among the outputs of the FFT 214. The pilots are specific subcarriers that are used when a transmitter transmits known values for synchronization of the receiver and transmitter in an OFDM system. In general, the OFDM system receiver is used for synchronization by using the complex values transmitted via the pilots among the outputs of the FFT.

A phase calculator 240 incudes a phase difference detector 216, a mean calculator 220, and a normalizer 222. The phase difference detector 216 detects a phase difference between a pair of pilots for one symbol. The mean calculator 220 averages the phase differences with respect to a plurality of pilot pairs. The normalizer 222 normalizes the mean value by dividing it into reference values corresponding to the volumes of phase changes occurring when an FFT window error of one sample exists. A normalized phase variation $\hat{\tau}_l$ calculated by the phase calculator 240 is expressed by the following Equation 2:

$$\hat{\tau}_l = \frac{1}{\frac{2\pi}{N}\frac{1}{L}\sum_{n=1}^{l}\frac{\Delta\phi_{l,k_{n+1,n}}}{k_{n+1}-k_n}} \qquad \text{...(2)}$$

wherein N is the number of useful data samples, L is the number of used pilots, k is a subcarrier number, $k_{n+1}-k_n$ is a frequency spacing between two pilot carriers, and $\Delta\phi_{l,k_{n+1,n}}$ is a phase difference between pilots for a l-th symbol.

The phase calculator 240 will now be described in more detail. The phase difference detector 218 detects a phase difference between the pilot pair extracted by the pilot extractor 216. Phase difference detection changes according to the method of allocating known complex values between the transmitter and receiver transmitted via pilots. The phase difference detector according to a first method comprises a phase detector (not shown) for detecting the phases of input complex values when an identical complex value is allocated to each pilot independently of symbols and pilots, and a

subtractor (not shown) for obtaining the difference between the phases calculated from the received complex values of two pilots. The phase difference detector according to a second method comprises a phase detector (not shown) for detecting the phase difference between an input complex value and a known complex value when different complex values are allocated for different pilots, and a subtractor (not shown) for obtaining the difference between the phases calculated from the received complex values of two pilots.

The mean calculator 220 averages a plurality of pilot pairs of the phase differences output by the phase difference detector 240 for an l-th symbol period.

A general OFDM system uses a plurality of pilots, and can obtain a more reliable value by averaging the pilots.

The normalizer 222 normalizes the mean calculated by the mean calculator 220 by dividing it into reference values. The reference value is set to be the magnitude of a phase change (N/2π) generated between two pilots when an FFT window offset is one sample.

The normalized phase variation output by the normalizer 222 is divided into an integer part and a fraction part by a round-off calculator 224 and a subtractor 226, and expressed by the following Equation 3:

$$\hat{\tau}_l = \gamma[\hat{\tau}_\mu] + \{\hat{\tau}_l - \gamma[\hat{\tau}_\mu]\} = (\textit{integer part}) + (\textit{fraction part}) \quad \ldots(3)$$

wherein $\gamma(\bullet)$ is a round-off function, and the fraction part is between ±0.5.

FIG. 3 is a conceptual view showing a division of time synchronization into an FFT window offset and a sampling clock offset by using the integer part and fraction part.

As shown in FIG. 3, the slope of a phase variation is affected by both the FFT window offset and the sampling clock offset. That is, when the FFT window offset is one sample, the slope of an actual phase variation is changed for each symbol on the axis of the slope of a phase variation with respect to an FFT window offset of one sample within an FFT window offset

decision area.

The FFT window 212 is controlled by an integer value output by the round-off calculator 224 because the FFT window offset is estimated in sample units.

The FFT window controller 228 receives the integer value output by the round-off calculator 224 and corrects FFT window position recovery errors of the FFT window 120.

The sampling clock offset of the ADC 210 is controlled to be within ±0.5. The PLL 230 receives a fraction value output by the subtractor 226 and controls the sampling clock offset of the ADC 210.

Consequently, the phase variation value output by the normalizer 222 simultaneously controls the FFT window via the round-off calculator 224 and the FFT window controller 228 and the sampling clock of the ADC 210 via the subtractor 226 and the PLL 230.

FIG. 4A is a graph showing outputs of the phase difference calculator 240 vs. FFT window offsets, according to the present invention. FIG. 4A shows normalized mean phase differences between two pilots output by the normalizer 222 when the FFT window offset is within±5 samples.

FIG. 4B is a graph showing inputs of the FFT window controller 228 vs. FFT window offsets, according to the present invention. FIG. 4B shows values of FIG. 4A which have passed through the round-off calculator 224, and accurately predicts FFT window errors with respect to the FFT window offsets.

FIG. 4C is a graph showing inputs of the PLL 230 for controlling sampling clock signals vs. FFT window offsets, according to the present invention. FIG. 4C shows the difference between the input and output values of the round-off calculator 224 output by the subtractor 226, representing an accurate characteristics curve which is not affected by the FFT window offset when the FFT window offset is within ±5 samples.

The present invention is not limited to the above embodiment, and it is apparent that modifications may be effected within the spirit of the present invention by those skilled in the art.

Industrial Applicability

According to the present invention as described above, FFT window position recovery is carried out without being affected by sampling clock errors, and simultaneously sampling clocks are controlled without being affected by FFT window position recovery errors. Therefore, causes of an unstable system are removed, and a synchronization time can be shortened by the simultaneous operations of the two functions.

What is claimed is:

1. A method of interlocking FFT window position recovery with sampling clock control in symbol units in an orthogonal frequency division multiplexing (OFDM) receiver for receiving an OFDM symbol consisting of a useful data interval and a guard interval, the method comprising the steps of:

(a) extracting a pilot signal from fast-Fourier-transformed OFDM received signals, and detecting inter-pilot phase differences;

(b) averaging phase differences detected in step (a) for a symbol and normalizing the mean phase difference by dividing it into reference values corresponding to phase differences generated when FFT window errors of at least one sample exist; and

(c) simultaneously controlling the FFT window position offset using a value obtained by rounding off the normalized value of the step (b), and the sampling clock offset using the difference between the round-off value and the normalized value.

2. The method of interlocking FFT window position recovery with sampling clock control in an OFDM receiver as claimed in claim 1, wherein the FFT window position offsets are controlled by integer values, and the sampling clock offsets are controlled by fraction values.

3. An OFDM receiver for interlocking FFT window position recovery with sampling clock control by receiving an OFDM symbol consisting of a useful data interval and a guard interval, the apparatus comprising:

an analog-to-digital converter (ADC) for converting an OFDM signal into digital complex samples;

an FFT window for removing the guard interval from the digital complex samples output by the ADC and outputting useful data samples;

an FFT for fast-Fourier-transforming the samples output by the FFT window;

a phase difference calculator for calculating phase differences between two values among the complex values received via a plurality of

pilots from the FFT, averaging these phase differences for one symbol, and normalizing the mean value by dividing it into predetermined reference values;

an FFT window controller for rounding off the normalized value output by the phase difference calculator and controlling the window position of the FFT window; and

a phase synchronous loop for controlling the sampling clock signals of the ADC using the difference between the round-off value and the normalized value.

4. The OFDM receiver for interlocking FFT window position recovery with sampling clock control as claimed in claim 3, wherein the phase difference calculator comprises:

a phase difference detector for detecting the phase differences between two pilots among the received complex values of pilots output by the FFT;

a mean calculator for averaging the phase differences detected by the phase detector for a symbol; and

a normalizer for normalizing the mean value obtained by the mean calculator by dividing it into reference values corresponding to phase differences generated when an FFT window error of one sample exists.

5. The OFDM receiver for interlocking FFT window position recovery with sampling clock control as claimed in claim 4, wherein the phase difference of the phase difference detector is set to be $\frac{\Delta\phi_{l,k_{n+1,n}}}{k_{n+1}-k_n}$, $k_{n+1}-k_n$ is a frequency spacing between two pilot carriers, and $\Delta\phi_{l,k_{n+1,n}}$ is an inter-pilot phase difference for an i-th symbol.

6. The OFDM receiver for interlocking FFT window position recovery with sampling clock control as claimed in claim 4, wherein the mean value of the mean calculator is set to be $\frac{1}{L}\sum_{n=1}^{L}\frac{\Delta\phi_{l,k_{n-1,n}}}{k_{n+1}-k_n}$, and L represents the number of used pilots.

7. The OFDM receiver for interlocking FFT window position recovery with sampling clock control as claimed in claim 4, wherein the normalization of the normalizer is carried out by multiplying $\frac{N}{2\pi}$ to the mean

value.

FIG. 1

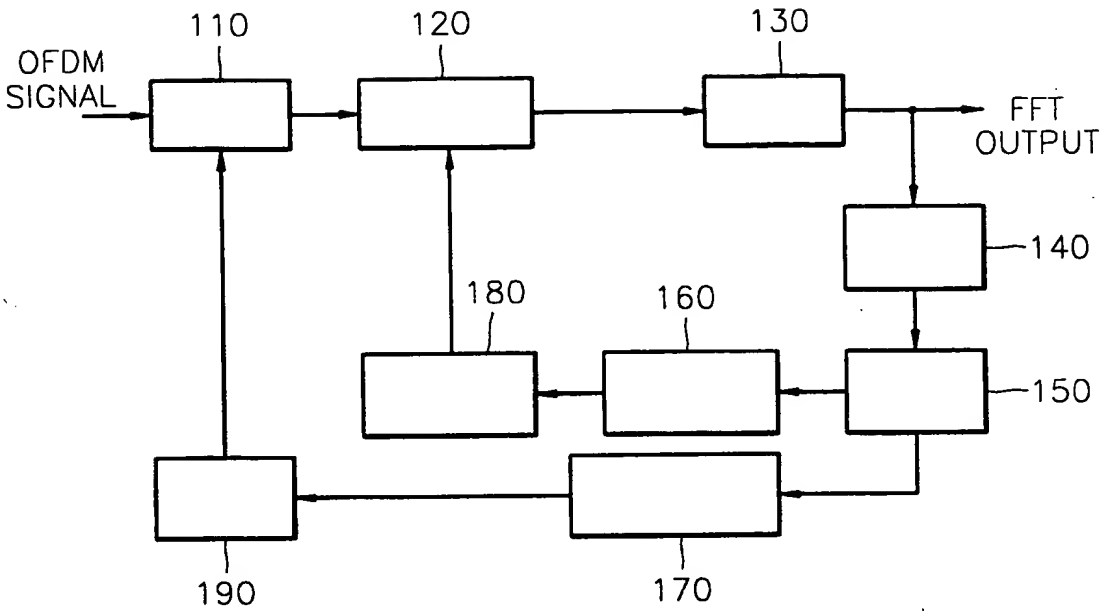

110
120
130
OFDM SIGNAL
FFT OUTPUT
140
180
160
150
190
170

FIG. 2

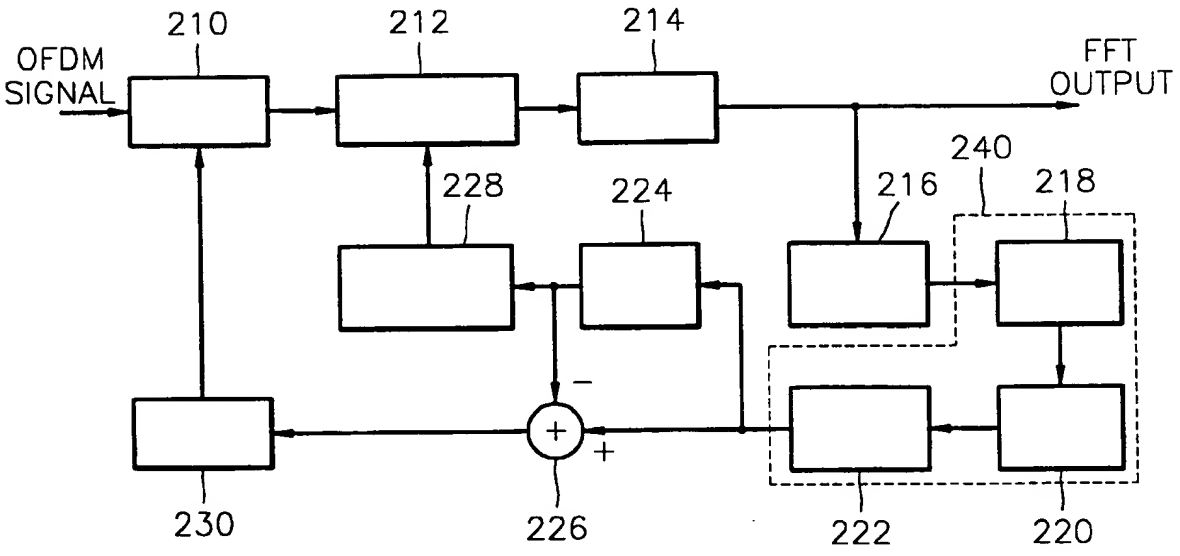

210
212
214
OFDM SIGNAL
FFT OUTPUT
240
228
224
216
218
230
226
222
220

FIG. 3

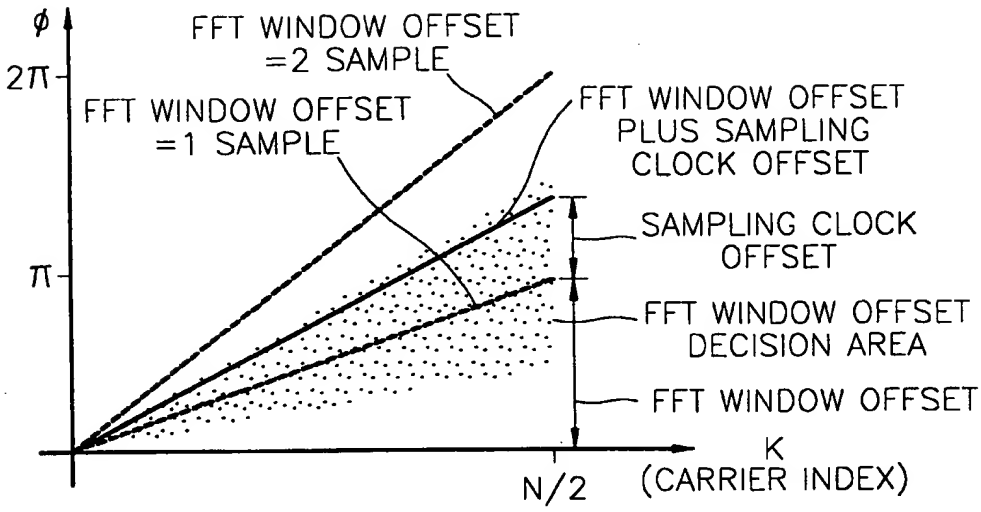

φ
2π
π
FFT WINDOW OFFSET
=2 SAMPLE
FFT WINDOW OFFSET
=1 SAMPLE
FFT WINDOW OFFSET
PLUS SAMPLING
CLOCK OFFSET
SAMPLING CLOCK
OFFSET
FFT WINDOW OFFSET
DECISION AREA
FFT WINDOW OFFSET
K
(CARRIER INDEX)
N/2

FIG. 4A

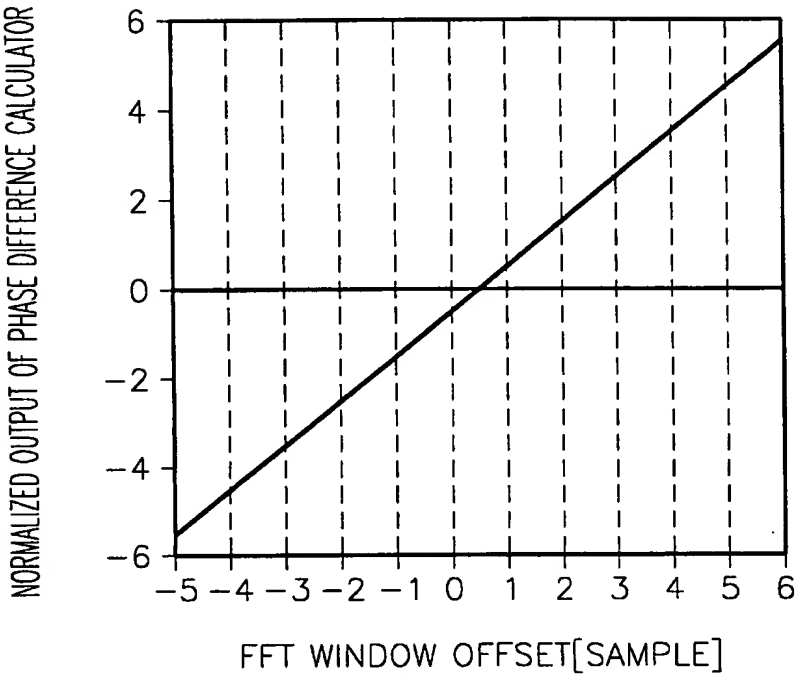

NORMALIZED OUTPUT OF PHASE DIFFERENCE CALCULATOR
6
4
2
0
−2
−4
−6
−5 −4 −3 −2 −1 0 1 2 3 4 5 6
FFT WINDOW OFFSET[SAMPLE]

FIG. 4B

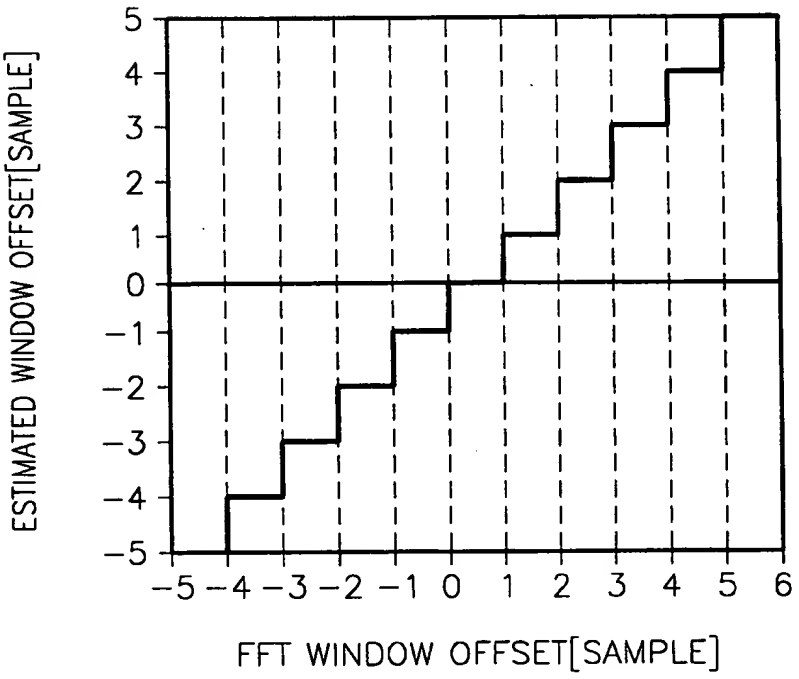
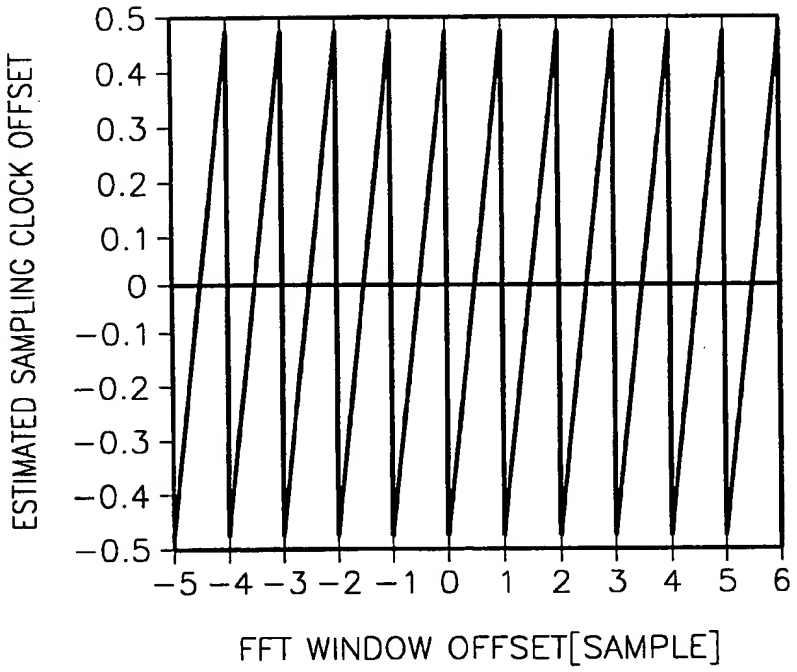

ESTIMATED WINDOW OFFSET[SAMPLE]
5
4
3
2
1
0
−1
−2
−3
−4
−5
−5 −4 −3 −2 −1 0 1 2 3 4 5 6
FFT WINDOW OFFSET[SAMPLE]

FIG. 4C


ESTIMATED SAMPLING CLOCK OFFSET
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−5 −4 −3 −2 −1 0 1 2 3 4 5 6
FFT WINDOW OFFSET[SAMPLE]

INTERNATIONAL SEARCH REPORT

Inter. ɔnal application No.
PCT/KR 98/00376

A. CLASSIFICATION OF SUBJECT MATTER

IPC^6: H 04 J 11/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC^6: H 04 J 11/00, H 04 H 1/00, H 04 L 5/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 683 576 A1 (HITACHI) 22 November 1995 (22.11.95), fig. 4; page 5, line 54 - page 6, line 32.	1,3
A	WO 92/10 043 A1 (THOMSON-CSF) 11 June 1992 (11.06.92), fig. 2,3; abstract.	1,3,4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 February 1999 (22.02.99)	24 February 1999 (24.02.99)

Name and mailing address of the ISA/ AT	Authorized officer
Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna	Dröscher
Facsimile No. 1/53424/535	Telephone No. 1/53424/320

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intc tional application No.

PCT/KR 98/00376

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WO A1 9210043	11-06-92	AT E 148970	15-02-97
		AU A1 90918/91	25-06-92
		AU B2 641071	09-09-93
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		DE T2 69124690	05-06-97
		EP A1 513313	19-11-92
		EP B1 513313	12-02-97
		ES T3 2098490	01-05-97
		FI A 923426	29-07-92
		FI A0 923426	29-07-92
		FR A1 2670062	05-06-92
		FR B1 2670062	12-11-93
		JP T2 5504037	24-06-93
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